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SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, Kohki Kanda, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Minoru Takahashi, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Katsumi Kiuchi, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Takao Koshikawa, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Katsuhide Sone, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan and Muneo Kamiguchi, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan have invented certain new and useful improvements in

MAGNETIC HEAD AND MAGNETIC DISK APPARATUS

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of which the following is a specification : -

1 TITLE OF THE INVENTION

MAGNETIC HEAD AND MAGNETIC DISK APPARATUS

5 CROSS-REFERENCE OF THE RELATED APPLICATION

This application is a Continuation-In-Part application of United States Patent Application No. 401,958 filed on March 10, 1995, now allowed.

10 BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a magnetic head used in a magnetic disk apparatus for recording information on and reproducing information from a recording medium.

15 Recently, as the scale of a magnetic disk apparatus has been reduced and the storage capacity thereof has been enlarged, the recording density of a recording medium has become high, and thus a magnetic head which floats low over the disk (small clearance) is required. However, because of the requirement that the magnetic head be resistant to shock, there is also a need to reduce occurrences of contact between the magnetic head and the disk.

2. Description of the Related Art

25 Figs. 1A, 1B and 1C show a construction of a conventional magnetic head. Referring to Fig. 1A, two rail surfaces 13a and 13b are formed on the surface of a core slider 12 of a magnetic head 11, which surface faces a magnetic disk (recording medium). The rail surfaces 13a and 13b are made to extend in the direction in which air flows. Tapered surfaces 14a and 14b which allow the head to float are formed on the side at which air enters the space between the head and the disk.

35 On an end face of the rail surface 13a at which face air exits the space between the head and the disk, a thin-film element 15 for writing and

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1 reading information is provided. As shown in Fig. 1B,
the thin-film element 15 is formed such that an
insulating film (alumina) 16 is formed on the end face
of the core slider 12 (rail surface 13a), and a
5 magnetic film 17 is formed on the insulating film 16.
An insulating film 18 is formed on the magnetic film
17, and a coil 19 is provided in the insulating film
18. A magnetic film 20 is formed on the insulating
film 18. Recording and reproduction are performed in
10 a gap 22 formed between the magnetic film 17 and the
magnetic film 20. A protective film (insulating film)
21 is formed on the magnetic film 20 in the thin-film
element 15. The shaded area indicates that portion of
the protective film which is susceptible to
15 temperature increase.

The rail surfaces 13a and 13b are chamfered
(applied with a lapping process) as indicated by
broken lines in Fig. 1C so as to allow air to flow
smoothly. Both the width and height of the chamfering
20 are 0 - 10 μ m. A distance L between the end face of
the core slider 12 and the end of the protective film
21 is set such that $L \geq 0.025$ mm. A distance S
(thickness of the protective film) between the
magnetic film 20 and the end of the protective film 21
25 is set such that $S \approx 0.015 - 0.02$ mm.

The magnetic head 11 is enabled to float
over the magnetic disk by receiving an air flow
generated by the rotating magnetic disk. In order
that damage caused by the contacting of the magnetic
30 head 11 with the magnetic disk be minimized, a thin
film of DLC (diamond-like carbon) or the like may be
provided on the rail surfaces 13a and 13b (including
the tapered surfaces 14a and 14b) and/or on the
magnetic disk, or burrs created by the chamfering of
35 the rail surfaces 13a and 13b may be removed.

Fig. 2 explains thermal expansion of the
protective film of the conventional magnetic head.

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1 Referring to Fig. 2, when the magnetic head 11 is
driven for a recording operation, the temperature of
the thin-film element 15 rises because a current is
fed to the coil 19, with the result that the
5 protective film 21 swells due to thermal expansion, as
indicated by a shaded end part 21' in Fig. 2. For
example, it was experimentally found that a swelling
of the protective film 21 of alumina measured 6 nm per
temperature rise of 10 °C.

10 Hence, the narrowest achievable separation
(clearance) between the magnetic head 11 and the
magnetic disk depends on the magnitude of the swelling
of the protective film 21 and on the spacing between
the head and the disk. Accordingly, frequent contacts
15 between the head and the disk may occur. Powder
created from abrasion damages the thin-film element 15
and the disk. Therefore, it becomes difficult to
secure small clearance.

Further, the chamfering of the rail surfaces
20 13a and 13b of the core slider 12 is done after a
wafer having the thin-film element 15 formed thereon
is cut and the rail surfaces 13a and 13b are formed.
If the chamfering process is applied to the thin-film
element 15, a variation in the quality of the produced
25 head results. For example, the electromagnetic
transducing property may deteriorate.

Furthermore, the conventional magnetic head
is liable to be affected by a fine projection located
on the magnetic disk. If the magnetic head is
30 affected by such a fine projection, an abnormal signal
will be superimposed on the read signal, as will be
described in detail later.

SUMMARY OF THE INVENTION

35 Accordingly, it is a general object of the
present invention to provide a novel and useful
magnetic head in which the aforementioned problems of

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1 the prior art are eliminated.

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5 A more specific object of the present invention is to provide an MR head and a magnetic disk apparatus equipped with the same in which the MR head has an improved structure which makes it possible for a fine projection on the magnetic disk to hit the MR head.

10 The above objects of the present invention are achieved by an MR head comprising: a slider; and a film structure part which is located on an air outflow side of the slider and includes an MR element for reproducing, the film structure part having an end surface located on an identical side as a floating surface of the slider, the end surface of the film structure part and the floating surface of the slider forming a step-like recess which has a depth making it possible to prevent a fine projection on a magnetic disk from hitting the end surface of the film structure part.

20 The MR head may be configured so that the depth of the step-like recess an end of the MR element on the end surface of the film structure part to be located on or above an imaginary line which passes through a rear edge of the slider and the end of the MR head when the MR head is in a floating state at a given floating angle.

30 The MR head may be configured so that: the depth of the step-like recess has a length equal to or greater than a sum of a first length and a second length; the first length causes an end of the MR element on the end surface of the film structure part to be located on an imaginary line which passes through a read edge of the slider that is in a floating state at a given angle and which is parallel to the magnetic disk; and the second length corresponds to a magnitude of a swelling of the end surface of the film structure part, the swelling being

1 formed when the film structure part is thermally deformed.

 The MR head may be configured so that: the depth of the step-like recess has a length equal to or greater than a sum of a first length and a second length; the first length causes an end of the MR element on the end surface of the film structure part to be located on an imaginary line which passes through a read edge of the slider that is in a floating state at a given angle and which is parallel to the magnetic disk; and the second length corresponds to a descending movement of the MR head after the MR head is pushed upwardly by the fine projection, the descending movement including an overshooting movement.

 The MR head may be configured so that: the depth of the step-like recess causes has a length equal to or greater than a sum of a first length, a second length, and a third length; the first length causes an end of the MR element on the end surface of the film structure part to be located on an imaginary line which passes through a read edge of the slider that is in a floating state at a given angle and which is parallel to the magnetic disk; the second length corresponds to a magnitude of a swelling of the end surface of the film structure part, the swelling being formed when the film structure part is thermally deformed; and the third length corresponds to a descending movement of the MR head after the MR head is pushed upwardly by the fine projection, the descending movement including an overshooting movement.

 The MR head may be configured so that the depth of the step-like recess satisfies the following condition:

$$Y1 \geq t1 \times \tan \alpha$$

where Y_1 is the depth of the step-like recess, t_1 is a distance between an air outflow end of the slider and the MR element, and α is the floating angle.

$$Y_3 \geq (t_1 \times \tan \alpha) + N_h$$

where Y3 is the depth of the step-like recess, t1 is a distance between an air outflow end of the slider and the MR element, α is the floating angle, and Nh is a magnitude of a swelling of the end surface of the film structure part, the swelling being formed when the film structure part is thermally deformed.

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$$Y_4 \geq (t_1 \times \tan \alpha) + Z$$

30

$$Y5 \geq (t1 \times \tan\alpha) + Nh + Z$$

where Y5 is the depth of the step-like recess, t1 is a distance between an air outflow end of the slider and

1 the MR element, α is the floating angle, N_h is a
magnitude of a swelling of the end surface of the film
structure part, the swelling being formed when the
film structure part is thermally deformed, and Z is a
5 descending movement of the MR head after the MR head
is pushed upwardly by the fine projection, the
descending movement including an overshooting
movement.

The above objects of the present invention
10 are also achieved by an MR head comprising: a slider;
and a film structure part which is located on an air
outflow side of the slider and includes an MR element
for reproducing, the film structure part having an end
15 surface located on an identical side as a floating
surface of the slider, the end surface of the film
structure part and the floating surface of the slider
forming a step-like recess which has a depth making it
possible to prevent a fine projection on a magnetic
20 disk from hitting the end surface of the film
structure part, and causes a first rear edge of the
film structure part to be located on or above an
imaginary line which passes through the first rear
edge of the film structure part and a second rear edge
25 of the slider when the MR head is in a floating state
at a given floating angle.

The MR head may be configured so that the
depth of the step-like recess satisfies the following
condition:

30
$$Y_2 \geq t_2 \times \tan \alpha$$

where Y_2 is the depth of the step-like recess, t_2 is a
thickness of the film structure part, and α is the
floating angle.

35 The MR head may be configured so that the
depth of the step-like recess satisfies the following
condition:

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Other objects and further features of the present invention will be apparent from the following detailed description when read in conjunction with the accompanying drawings, in which:

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Fig. 2 explains thermal expansion of a protective film of a conventional magnetic head:

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Figs. 4A and 4B show a relative position of a magnetic head according to the first embodiment with respect to a recording medium;

30

35

Fig. 7 explains a relationship between a

Fig. 8 is a bottom view of the magnetic head;

Figs. 10A and 10B show parts of a thin-film element:

Figs. 12A and 12B show a part of the wafer in which the thin-film element is formed;

Figs. 14A and 14B show a construction of a magnetic head of a second embodiment;

Figs. 16A and 16B show a construction of a magnetic head of a third embodiment;

25 Figs. 18A and 18B explain other shapes of
the groove of the first through third embodiments;

30 Figs. 20A, 20B and 20C show a construction of a part of a magnetic head of a fourth embodiment of the present invention;

35 Figs. 22A, 22B and 22C are respectively
diagrams of a conventional MR head;

Fig. 23 is an enlarged side view of an MR

Fig. 24A is a perspective view of the MR head according to the fifth embodiment of the present invention;

10 Figs. 25A, 25B, 25C, 25D, 25E, 25F and 25G are diagrams showing a function of a step-like recess formed in the MR head according to the fifth embodiment of the present invention;

Figs. 27A, 27B, 27C and 27D are diagrams showing a function of a step-like recess formed in the MR head according to the sixth embodiment of the present invention;

Fig. 29 is an enlarged side view of an MR head according to an eighth embodiment of the present invention;

Fig. 31 is an enlarged side view of an MR head according to a ninth embodiment of the present invention;

Fig. 33 is a plan view of another magnetic disk apparatus equipped with the MR head of the present invention; and

Fig. 34 is an enlarged perspective view of a

1 suspension of the magnetic disk apparatus shown in
Fig. 33.

DETAILED DESCRIPTION

5 Figs. 3A and 3B show a construction of the
magnetic head of a first embodiment of the present
invention. Referring to Fig. 3A, two rail surfaces
33a and 33b are formed on the surface of a core slider
32 of a magnetic head 31 which surface faces a
10 magnetic disk (recording medium). The rail surfaces
33a and 33b are made to extend in the direction in
which air flows. Tapered surfaces 34a and 34b for
allowing the head to float are formed on an end of the
core slider 32 at which end air is introduced into the
15 space between the head and the disk.

On one end of each of the rail surfaces 33a
and 33b, at which end air exits, a thin-film element
35 for writing and reading information and a
protective film 36 are provided. As shown in Fig. 3B,
20 the thin-element 35 is formed such that an insulating
film 37 is formed on the end face of the core slider
32 (rail surfaces 33a and 33b), and a magnetic film 38
serving as a magnetic pole is formed on the insulating
film 37. An insulating film 39 is formed on the
25 magnetic film 38, and a coil 40 having a predetermined
number of turns is provided in the insulating film 39.

A magnetic film 41 serving as a magnetic
pole is provided on the insulating film 39. Recording
and reproduction are performed in a gap 42 formed
30 between the magnetic film 38 and the magnetic film 41.
The protective film (insulating film) 36 is formed on
the magnetic film 41 in the thin-film element 35.

A step-like recess 43a is formed in each of
the rail surfaces 33a and 33b, respectively, near the
35 thin-film element 35 so as to extend longitudinally
toward an end of each of the rail surfaces at which
air exits. A distance S (Fig. 3B) between the

1 magnetic film 41 and the end of the protective film 36
is set such that S is as close as possible to zero,
and at least smaller than 0.015 mm.

5 The rail surfaces 33a and 33b are chamfered
(applied with a lapping process) as indicated by
broken lines in Fig. 3A so as to allow air to flow
smoothly and to reduce the amount of powder created
when the disk comes into contact with the head and is
thus abraded.

10 While the thin-film elements 35 is formed on
the end face of both the rail surfaces 33a and 33b,
only one of the elements 35 is driven during a normal
operation. This is to ensure that the thin-film
elements 35 of the magnetic heads 31 over the
15 respective surfaces of the magnetic disk are aligned.
Alternatively, only one element may be provided at the
center of the end of the core slider.

Typically, as indicated in Figs. 3A, the
dimensions of the magnetic head of Fig. 3 are: $a \geq$
20 $0.03 \mu\text{m}$; $b = 0.045 \text{ mm}$; $c = 25 \mu\text{m}$; $d = .40 \mu\text{m}$; $e = 2 \text{ mm}$;
 $f = 1.6 \text{ mm}$; $g = 0.385 \text{ mm}$; $h = 0.054 \text{ mm}$; and $i = 0.255$
mm. Alternatively, the dimensions may be set such
that $0.01 \text{ mm} \leq c \leq 0.25 \text{ mm}$, and $L \geq 0.02 \text{ mm}$.

The chamfering of the protective film in
25 which a recess is provided will be discussed below.

Fig. 4A is a schematic diagram showing the
relative position of the magnetic head according to
the first embodiment with respect to the recording
medium. Fig. 4B is an enlarged view of the end of the
magnetic head at which end air exits. The dimension
30 indicated in Fig. 3A as a is indicated as RE in Fig.
4A. Desirably, RE has a value of $0.03 \mu\text{m}$ or greater.

Referring to Fig. 4A, FHT indicates a
distance between the recording medium and the magnetic
head, FHL indicates a distance between the air-
35 entering end of the flat part of the core slider and
the recording medium, SL indicates a length, as

1 measured in the longitudinal direction, of the rail
surfaces 33a and 33b, and AH indicates a thickness of
the protective film, the length SL not including the
tapered portion formed in the air-entering end of the
5 core slider.

Referring to Figs. 4A and 4B, x indicates a
distance between the end of the protective film and
the recording medium, and θ indicates an inclination
of the magnetic head. x and θ are given by the
10 following equations.

$$\begin{aligned}\theta &= \sin^{-1} \{ (FHL - FHT) / SL \} \\ x &= RE \cos \theta - AH \sin \theta + FHT \\ (E_k &= RE \cos \theta, E_j = AH \sin \theta)\end{aligned}$$

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It is preferred that, if RE has a value
smaller than 0.03 μm , the end of the protective film
be chamfered. In other words, a taper may be formed
at the end of the protective film.

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It is assumed that a magnetic disk apparatus
1 has a magnetic head whose dimensions are; $RE = 0.02$
 μm , $FHT = 0.1 \mu\text{m}$, $FHL = 0.35 \mu\text{m}$, $SL = 1.85 \times 10^3 \mu\text{m}$,
 $AH = 45 \mu\text{m}$. The values of x and θ in the apparatus 1
are as follows.

25

$$\begin{aligned}\theta &= \sin^{-1} \{ (FHL - FHT) / SL \} \\ &= \sin^{-1} \{ (0.35 - 0.1) / (1.85 \times 10^3) \} \\ &= 0.00774 \text{ [deg]} \\ x &= RE \cos \theta - AH \sin \theta + FHT \\ 30 \quad &= 0.02 \cos \theta - 45 \sin \theta + 0.1 \\ &= 0.11392 \text{ [}\mu\text{m]}\end{aligned}$$

It is further assumed that a magnetic disk
apparatus 2 has a magnetic head whose dimensions are;
35 $RE = 0.01 \mu\text{m}$, $FHT = 0.07 \mu\text{m}$, $FHL = 0.245 \mu\text{m}$, $SL = 1.85$
 $\times 10^3 \mu\text{m}$, $AH = 45 \mu\text{m}$. The values of x and θ in the
apparatus 2 are as follows.

1

$$\begin{aligned}\theta &= \sin^{-1}\{(FHL - FHT)/SL\} \\ &= \sin^{-1}\{(0.245 - 0.07)/(1.85 \times 10^3)\} \\ &= 0.00542 \text{ [deg]}\end{aligned}$$

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$$\begin{aligned}x &= RE\cos\theta - AH\sin\theta + FHT \\ &= 0.01\cos\theta - 45\sin\theta + 0.07 \\ &= 0.07574 \text{ [\mu m]}\end{aligned}$$

When an element in a magnetic disk apparatus is energized, the temperature of the coil rises, and the protective film is made to swell toward the medium accordingly. Fig. 5 explains a variation of a difference (hereinafter, referred to as a recess amount) between x and FHT under different temperature rise conditions. A negative recess amount indicates that the end of the protective film is nearer the medium than the FHT gap is. It will be learned from Fig. 5 that, for each temperature rise of 10°C , the recess amount decreases by about 6 nm. When the temperature rise is equal to 50°C , the end of the protective film is nearer the medium than the FHT gap by a margin of 25 nm. It is determined from this that, if the length GD indicated in Fig. 4B is reduced by about 30 nm, the projection of the protective film beyond the FHT gap is prevented.

In order to prevent the projection of the protective film beyond the recording gap, a taper must be formed at the end of the protective film. Figs. 6A and 6B are schematic diagrams showing the relative position of the magnetic head according to a variation of the first embodiment with respect to the recording medium. A broken line in Fig. 6A indicates a taper. A point D' in Fig. 6B indicates the end of the swollen protecting film. Assuming that DE is 1, four cases of taper formation will be considered.

Case 1: $A'E = 0.8$

Case 2: $A'E = 0.6$

1 Case 3: $A'E = 0.4$

Case 4: $A'E = 0.2$

Theoretically, on the basis of the similarity between a triangle $A'FD$ and a triangle $A'D'D$, it will be determined that the degree of swelling of the protective film is in inverse proportion to a ratio of $A'E$ to DE . That is, the shorter the length $A'E$, the smaller the degree of swelling of the protective film.

10 Fig. 7 explains a relationship between the length ($A'E$) of a non-tapered portion and the recess amount under different temperature rise conditions. Fig. 7 indicates that, for each temperature rise of 10°C , the recess amount decreases by about 6 nm. A shaded range in Fig. 7 indicates a range in which the protective film has a wider clearance than the recording gap with respect to the recording medium.

Assuming that the temperature rise due to the energization of the element is 30°C at the most, a taper formation resulting in the length $A'E$ of $25\text{ }\mu\text{m}$ gives a satisfactory performance of the magnetic head. Fig. 8 is a bottom view of the magnetic head when $A'E = 25\text{ }\mu\text{m}$.

Fig. 9 explains a wafer process for producing a thin-film element, and Figs. 10A and 10B show parts of the thin-film element. Referring to Fig. 9 and Figs. 10A/10B, the insulating film 37 is formed, by alumina sputtering, on the surface of a wafer 44 as an underlying film, the thickness of the wafer 44 corresponding to the length of the core slider 32 (ST 1). The lower magnetic film 38 is formed on the insulating film 37 by a subsequent chromium plating process and an etching process (ST 2).

35 The number of the magnetic films 38 formed depends on the number of thin-film elements 35 formed in the wafer 44. The gaps 42 formed in the magnetic

1 film 38 are linearly arranged.

Subsequently, a gap film 39a is formed on the magnetic film 38 by alumina sputtering and milling (ST 3). A lower insulating film 39b is formed on the gap film 39a by alumina photo etching (ST 4). A coil film 40a is formed on the lower insulating film 39b by chromium sputtering and photo etching (ST 5). When the coil 40 is formed of two layers, an insulating film 39c is formed after ST 4 and ST 5, and lastly an upper coil film 40b is formed. An upper insulating film 39d is formed on the upper coil film 40b by alumina photo etching (ST 6).

An upper magnetic film 41 is formed on the upper insulating film 39d by chromium plating and etching (ST 7). The gap 42 is formed between the upper magnetic film 41 and the lower magnetic film 38, in which gap the gap film 39a is formed.

Bumps serving as lead connecting parts of the magnetic films 38 and 41, and coil films 40a and 40b are formed by chromium sputtering or the like (ST 8). Thus, the thin-film element 35 is completed. The protective film 36 is formed on the entirety of the thin-film element 35 by alumina sputtering (ST 9).

The recess 43a (a broken line in Fig. 10A) is formed by etching the protective film 36 or by grinding the same with a grindstone or the like (ST 10; see Fig. 10B).

Figs. 11A, 11B, 11C and 11D explain a fabrication process of the magnetic head and the building of a head assembly, and Figs. 12A and 12B show a part of the wafer in which the thin-film element is formed.

Referring to 11A, 11B, 11C and 11D, the wafer 44, in which the thin-film element 35 and the protective film 36 (recess 43a) are formed, is cut along a line along which pairs of the gaps 42 of the thin-film element 35 face each other so that a cut

Fig. 13 is a plan view showing a construction of a magnetic disk apparatus 61 in which the magnetic head of Figs. 3A and 3B is used. In the magnetic disk apparatus 61 shown in Fig. 13, the head assembly 51 is fitted on an arm 63 of an actuator 62, the base of the arm 63 being rotatably supported by a

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1 disk 69 and the magnetic head 31, with the result that
the damage to the magnetic head 31 (thin-film element
35) due to the attachment of abrasion powder thereto
is diminished, and the reliability of the apparatus is
5 increased. Consequently, the magnetic head 31 is
allowed to approach the surface of the magnetic disk
69 more closely during the operation, that is, a small
clearance can be achieved. Moreover, the recess 43a
can be easily formed in the wafer that is being
10 processed during production of the magnetic head 31.
The presence of the recess 43a reduces the distance
between the gap 42 and the end of the protective film
36, thereby affecting the thin-film element 35 less
unfavorably than when a recess is formed by chamfering
15 the rail surfaces 33a and 33b according to the
conventional process. As a result, variation in the
quality of the magnetic head produced can be
decreased.

The recess 43a also reduces the chances of
20 the edge of the magnetic head 31 coming into contact
with the magnetic disk 69 due to rolling of the
magnetic head 31.

Figs. 14A and 14B show a construction of the
magnetic head according to a second embodiment of the
25 present invention. The magnetic head 31 shown in
Figs. 14A and 14B is constructed such that a tapering
recess 43b is formed in each of the rail surfaces 33a
and 33b (surfaces which face the disk) of the core
slider 32, near the thin-film element 35, the tapering
30 recess 43b extending longitudinally toward an end of
each of the rail surfaces at which air exits. The
remaining aspects of the construction are the same as
those of the first embodiment and have the same
effect. The magnetic head 31 shown in Figs. 14A and
35 14B is mounted on the magnetic disk apparatus 61 shown
in Fig. 11. Typically, the dimension indicated by x
is approximately 0.020 mm, and the dimension indicated

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1 by y is 0.045 mm.

Figs. 15A and 15B explain how the magnetic head 31 of the second embodiment is produced. Referring to Figs. 15A and 15B, a predetermined number of the thin-film elements 35 are produced on the wafer 44, similarly to the method explained in Fig. 9, and the protective film 36 is formed on the thin-film elements 35. Thereafter, a groove 73a having a cross section of a letter V is formed near the gap 42 of each of the thin-film elements 35 by means of a blade (grindstone or the like) having a V-shaped cross section. For example, the wafer is fixed on a stage, whereupon a grindstone held by a robot hand is moved, in the transversal direction, and positioned at a part of each block of the wafer, at which part the thin-film element is formed, the positioning being done by sensing marks. The grindstone is driven in the longitudinal direction of the wafer so as to form the groove 73a.

20 By cutting the wafer 44 along the groove 73a having a cross section of a letter V, the tapering recess 43b as shown in Figs. 14A and 14B is formed to extend from the neighborhood of the thin-film element 35 to the protective film 36.

25 Thus, the tapering recess 43b can be easily formed in the wafer that is being processed by the blade 72.

In this construction, when the magnetic head 31 is driven by feeding a current to the coil, the temperature may rise and the protective film 36 may undergo a thermal expansion. However, only a small degree of swelling of the protective film 36 on the rail surfaces 33a and 33b (the gap 42) results, as indicated by a broken line in Fig. 14B. Therefore, it is possible to achieve a small clearance of the magnetic head 31.

Figs. 16A and 16B show a construction of the

1 magnetic head of a third embodiment of the present
invention, and Fig. 17 explains a shape of a groove of
the third embodiment. The magnetic head 31 shown in
Figs. 16A and 16B is constructed such that a curved
5 recess 43c is formed in each of the rail surfaces 33a
and 33b (surfaces which face the disk) of the core
slider 32, near the thin-film element 35, the curved
recess 43c extending longitudinally toward an end of
each of the rail surfaces at which air exits. The
10 remaining aspects of the construction are the same as
those of the first embodiment and have the same
effect. The magnetic head 31 shown in Figs. 16A and
16B is mounted on the magnetic disk apparatus 61 shown
in Fig. 13.

15 As shown in Fig. 17, a groove 73b having a
cross section of an inverted letter R is formed by a
blade having a curved cross section, near the gap 42
of each thin-film element 35. By cutting the wafer
along the center line of the groove 73b, the recess
20 43c having a cross section of an inverted letter R is
formed in the protective film 36.

By forming the recess 43c, only a small
degree of swelling of the protective film 36 on the
rail surfaces 33a and 33b (the surfaces that face the
25 disk) due to a thermal expansion results, as indicated
by a broken line in Fig. 16B. Therefore, it is
possible to achieve a small clearance of the magnetic
head 31.

Figs. 18A and 18B explain other possible
30 configurations of the groove in the first through
third embodiments. Fig. 18A shows a case where a
blade having a cross section of an inverted trapezoid
is applied to the wafer being processed so as to form
a groove 73c having a cross section of an inverted
35 trapezoid, near the gap 42 of the thin-film element
35. By cutting the wafer along the center line of the
groove 73c having a cross section of an inverted

1 trapezoid, a tapering recess is formed in the
protective film 36.

5 Fig. 18B shows a case where a blade is
applied to the wafer being processed so as to form a
groove 73d having a flat bottom and a cross section of
an inverted letter R, near the gap 42. By cutting the
wafer at the center line of the groove 73d, the recess
having a cross section of an inverted letter R is
formed in the protective film 36.

10 Figs. 19A and 19B show a construction of the
magnetic head in which a thin-film MR element is used.
Fig. 19A shows a construction of a part of the
magnetic head, Fig. 19B being a partial cross
sectional view thereof. A magnetic head 81 shown in
15 Figs. 19A and 19B is configured such that the
insulating film 37 of alumina or the like is formed as
an underlying layer on the core slider 32, a shield
film 82 (magnetic film) of FeMn (manganese iron) or
the like is formed on the insulating film 37, and an
20 insulating film 83a of alumina or the like is formed
on the film 82.

 An MR element (magnetoresistant effect
element) 84 and conductive members 85a and 85b (the
member 85b is not shown in the figure) connected to
25 respective ends of the MR element 84 are formed on the
insulating film 83a. An insulating film 83b is formed
on the MR element 84 and the conductive members 85a
and 85b.

 The lower magnetic film 38 serving as a
30 shield film is formed on the insulating film 83b.
Similarly to the magnetic head of Figs. 3A and 3B, the
insulating film 39, the coil 40 and the upper magnetic
film 41 are formed on the magnetic film 38. Thus, the
thin-film element 35 is completed. The protective
35 film 36 is formed on the thin-film element 35. The
step-like recess 43a is formed on the protective film
36. The recess 43a may have a tapering or curved

1 cross section.

In the magnetic head 81 of the above construction, the gap 42 in the thin-film element 35 serves as an element for recording information, and
5 the MR element 84 serves as an element for reproducing information.

Thus, even in the case where the MR element 84 is used, the recess 43a formed in the protective film 36 reduces the chances of the magnetic head 81
10 coming into contact with the magnetic disk 69 when the temperature rises. Consequently, it is possible to achieve a small clearance of the magnetic head 81.

The MR element 84 may also be used in a fourth embodiment described below.

15 Figs. 20A, 20B and 20C show a construction of a part of the fourth embodiment of the present invention. Fig. 20A is a plan view of the part including a thin-film element, Fig. 20B is a rear view of an end face of the protective film, and Fig. 20C is
20 a side view of the part including the thin-film element. A magnetic head 91a shown in Figs. 20A - 20C has a construction similar to that shown in Fig. 1A. However, the protective film 36 is formed on the thin-film element 35, and two grooves 92a and 92b having a
25 cross section of a letter V are formed to extend from the neighborhood of the thin-film element 35 to the end of the protective film 36, at which end air exits, the grooves 92a and 92b becoming increasingly deeper as they approach toward the end of the protective film
30 36. Further, as shown in Fig. 20C, two grooves 93a and 93b (the groove 93b is not shown in the figure) having a cross section of a letter V are formed at the respective sides of the end of the protective film 36 so as to extend toward the end of the protective film,
35 at which end air exits, the grooves 93a and 93b becoming increasingly deeper as they approach toward the end of the protective film 36. The magnetic head

The above construction, in which the grooves 92a and 92b are formed on the surface of the protective film 36, which surface faces the disk, and the grooves 93a and 93b are formed on the sides of the protective film 36, ensures that the cooling effect is improved, that the surface area near the thin-film element 35 is increased, and that only a small degree of swelling, induced by the temperature rise, of the protective film 36 occurs in the surface thereof facing the disk. Accordingly, it is possible to achieve a small clearance of the magnetic head 91a with respect to the magnetic disk.

The magnetic head 91b shown in Figs. 21A, 21B and 21C is constructed such that step-like recesses 94a and 94b are formed by mask ion milling or the like so as to extend along both sides of the thin-film element 35 from the neighborhood of the thin-film element 35 to the end of the protective film 36, at which end air exits. Further, as shown in Fig. 21C, grooves 95a and 95b (the groove 95b is not shown in the figure) having a cross section of a letter V are formed, for example, by grinding, on the sides of the protective film 36, the grooves 95a and 95b becoming increasingly deeper as they approach toward the end of the protective film 36.

The steps 94a and 94b and the grooves 95a and 95b on both sides of the film 36 ensure that the surface area near the thin-film element 35 is increased, that the cooling effect is increased, and

While the fourth embodiment has been described assuming that the grooves 92a, 92b, 93a, 93b, 95a, and 95b having a cross section of a letter V and steps 94a and 94b are formed to extend from the neighborhood of the thin-film element 35 to the protective film 36, any configuration is acceptable as long as the requirement of increasing the surface area is met.

A description will be given of fifth through ninth embodiments of the present invention. The fifth through ninth embodiments are further improvements in the MR head. In order to facilitate understanding of the fifth through ninth embodiments of the present invention, related prior art will be described below.

35 Figs. 22A and 22B show a conventional MR head 110, which includes a slider 111 and a film structure part 112 located on an air outflow end

1 surface 111a of the slider 111. The film structure
part 112 has an MR element 113. An end surface 112a
of the film structure part 112 is located on an
extension of a floating surface 111b of the slider
5 111b. That is, the end surface 112a of the film
structure part 112 continues to the floating surface
111b.

When a magnetic disk 120 is rotated in a
direction indicated by an arrow CC, the MR head 110
10 continues to float over an upper surface 120a of the
magnetic disk 120 due to an air flow 120A so that the
MR head 110 is located at a floating height h and is
inclined at an angle α so that the side of the head on
which the element 113 is located is closer to the
15 magnetic disk 120 than the air inflow end surface of
the slider 111. In the above floating state, the MR
head 110 reads a signal recorded on the magnetic disk
120.

Generally, the magnetic disk has a substrate
20 having a surface which is subjected to texturing in
order to prevent the magnetic head from being sucked
to the magnetic disk when the magnetic head starts to
relatively move from a state in which the magnetic
head is in contact with the magnetic disk. A film is
25 formed on the textured surface of the substrate. A
roughness R_a formed on the textured surface of the
magnetic disk is approximately equal to 10 to 50 Å, so
that the MR head in the floating state does not come
into contact with the magnetic disk.

30 The textured surface of the magnetic disk
can be formed by a mechanical process or by using a
laser beam. In practice, as shown in Fig. 22B, a fine
projection 121 protruding from the upper surface 120a
is formed.

35 The amount h of the floating of the MR head
is as small as 30 - 50 nm due to an increase in the
recording density. As shown by a two-dot chained line

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[illegible]

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Hence, the fifth through ninth embodiments of the present invention are to provide an MR head and a magnetic disk apparatus equipped with the same in which the MR head has an improved structure which makes it possible for a fine projection on the magnetic disk to hit the MR head.

5 The MR head 130 includes an air inflow end 131, and an air outflow end 132. The MR head 130 has a slider 133 and a film structure part 134. The slider 133 is made of, for example, Al_2O_3 or TiC, and has a block-shaped structure. The film structure part 134 is formed by a process of producing a film in the semiconductor field. The slider 133 has a lower surface, which faces a magnetic disk in a magnetic disk apparatus in which the MR head 130 is provided. The lower surface has two rails 133a and 133b, and a shallow recess portion 133c located between the rails 133a and 133b. The rails 133a and 133b and the recess portion 133c extend in the direction CC. The respective lower surfaces 133d and 133e of the rails 133a and 133b function as floating surfaces. An edge 133g (Fig. 23) is defined by the floating surface 133f and a surface 133d of the air outflow end 132.

The film structure part 134 is located on the surface 133f of the air outflow end 132 and is located on the side of the rail 133a. As shown in Fig. 23, the film structure part 134 includes a stacked structure, in which stacked are an insulating film 140, a lower shield film 141, an insulating film 142, an MR element 143, electrically conductive members 144 (only one member 144 appears in the figure), an insulating film 145, a lower magnetic film 146, an insulating film 147, a film-shaped coil 148, an upper magnetic film 149 and a protection film 150. The insulating film 140, which serves as an underlying layer, is made of, for example, alumina, and is provided on the surface 133f of the slider 133. The lower shield film 141 is made of, for example, FeN (ferri nitride). The insulating films 142 and 145 are

1 made of, for example, alumina. The element 143 has a
film shape. The conductive members 144 have a film
shape, and are electrically connected to the
respective ends of the element 143. The lower
5 magnetic film 146 functions as a shield film.

The ends of the conductive elements 144
other than the ends thereof connected to the MR
element 143 are exposed as terminal parts 144' of the
MR element 143. The ends of the coil 148 are exposed
10 as terminal parts 148' of an inductive head. The
terminal parts 144' and 148' are soldered to lead
lines, which are also connected to a head IC for
driving the heads provided in the magnetic disk
apparatus shown in Fig. 13.

15 The magnetic disk apparatus 61 can include a
plurality of magnetic disks arranged in a stacked
formation. In this case, a plurality of pivoting arms
equipped with MR heads are respectively provided for
the magnetic disks.

20 The film structure part 134 has an end
surface 151 located on the same side as that of the
floating surface 133d.

The lower magnetic film 146, the insulating
film 147, the film-shaped coil 148 and the upper
25 magnetic film 149 form a recording dedicated element.
The MR element 143 functions as a reproduction
dedicated element. The end surface 151 is lower than
the floating surface 133d so that the end surface 151
has a step-like recess 152 having a step size (depth)
30 Y1 shown in Fig. 23. The end surface 151 is parallel
to the floating surface 133d. The step-like recess
152 can be formed by a mechanical polishing process
using an appropriate stone or a polishing process such
as ion trimming.

35 The depth of the step-like recess 152, that
is, the step size Y1 is selected so that it satisfies
the following condition:

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$$Y1 \geq t1 \times \tan \alpha$$

5

where $t1$ is the distance between the surface 133f of the slider 133 and the MR element 143, and α is the floating angle (radian) of the MR head 130. The above distance corresponds to the sum of the thicknesses of the insulating film 140, the lower shield film (magnetic film) 141 and the insulating film 142.

10

The floating angle of the MR head 130 is, for example, 0.20 radian, and the distance $t1$ is, for example, 10 μm . In this case, the step size $Y1$ is approximately 2 μm .

15

Fig. 23 shows a state in which the MR head 130 is inclined at the floating angle α . An imaginary plane 155 will now be considered which passes on the edge 133g and is parallel to the magnetic disk. In this state, the step size $Y1$ contributes to positioning the end portion of the MR element 143 over the imaginary plane 155.

20

A description will now be given, with reference to Figs. 25A through 25G, of the function of the step-like recess 152 of the MR head 130 in operation of the magnetic disk apparatus 161.

25

As shown in Fig. 25A, a flow of air 120A is caused when the magnetic disk 120 is rotated in the direction CC. The MR head 130 is made float over the upper surface 120a of the magnetic disk 120 due to the function of the flow 121 of air. In this state, the MR head 130 has the amount h of floating, and is inclined at the floating angle α so that the rear side of the MR head 130 on which the MR element 143 is located is closer to the magnetic disk 120 than the front side thereof. In this state, a desired track formed on the magnetic disk 120 can be accessed and information can be read therefrom or recorded thereon via the MR head 130.

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1 As shown in Figs. 25B, 25D and 25F, in
practice, fine projections 121-1, 121-2 and 121-3
having different sizes may be formed on the upper
surface 120a of the magnetic disk 120 during the
5 production process. The fine projection 121-1 has a
height b_1 , which is less than the amount (height) h of
floating, as shown in Fig. 25B. The fine projection
121-2 has a height b_2 , which is approximately equal to
the floating height h , as shown in Fig. 25D. The fine
10 projection 121-3 has a height b_3 , which is greater
than the floating height h by a length A , as shown in
Fig. 25F.

As shown in Fig. 25B, the fine projection
121-1 can pass below the MR head 130 without hitting
15 the end surface 151 of the film structure part 134.
Hence, the envelope of the read signal obtained in
that state is as shown in Fig. 25C, in which no
abnormal signal due to the thermal asperity can occur.

As shown in Fig. 25D, the fine projection
20 121-2 hits the end surface 151 of the film structure
part 134. However, it should be noted that the fine
projection 121-2 hits a rear portion 151a of the end
surface 151, the rear portion 151a being located on a
downstream side of the MR element 143. Thus, the fine
25 projection 121-2 does not hit the MR element 143.
Hence, the envelope of the read signal obtained in
this case does not have any abnormal signal due to the
thermal asperity, as shown in Fig. 25E.

As shown in Fig. 25F, the fine projection
30 121-3 hits a portion of the slider 133 in the vicinity
of the edge 133g, and pushes the MR head 130 upwardly.
Then, the MR head 130 descends. While the MR head is
descending after it is pushed upward, the fine
projection 121-3 may hit the MR element 143. Even if
35 the fine projection 121-3 hits the MR element 143, the
amount of energy applied to the MR element 143 at this
time is much less than that applied to the MR element

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1 143 when the fine projection 121-3 directly hits the
MR element 143. Hence, the envelope of the read
signal obtained at this time is as shown in Fig. 25G,
in which a small abnormal signal due to the thermal
5 asperity is superimposed on the read signal.

A description will now be given, with reference to Fig. 26, of a sixth embodiment of the present invention. In Fig. 26, parts that are the same as those shown in the previously described figures are given the same reference numbers. An MR head 130A shown in Fig. 26 has the end surface 151 of the film structure part 134 having a step-like recess 152A of a step size Y2 with respect to the floating surface 133d. The depth of the step-like recess 152A, that is, the step size Y2, satisfies the following condition:

$$y_2 \geq t_2 \times \tan \alpha$$

20 where t2 is the thickness of the film structure part 134, and α is the floating angle of the MR head 130A. The step size Y2 is greater than the step size Y1 of the fifth embodiment of the present invention.

As shown in Fig. 27A, the aforementioned
fine projection 121-2 can pass below the MR head 130A
without hitting the end surface 151 of the film
structure part 134, as in the case of the fine
projection 121-1 which has been described with
reference to Fig. 25B. The envelope of the read
signal obtained in the case shown in Fig. 27A does not
have any abnormal signal due to the thermal asperity.

As shown in Fig. 27C, the fine projection 121-3 hits a portion in the vicinity of the edge 133g of the floating surface 133d of the slider 133. The MR head 130A is pushed upwardly by the fine projection 121-3, and then descends. Since the step size Y2 is greater than the step size Y1, the MR element 143 hits

1 a rear portion of the fine projection 121-3. Hence,
the possibility that the fine projection 121-3 hits
the MR element 143 when the MR head 130A descends can
be reduced. Even if the fine projection 121-3 hits
5 the MR element 143, the MR element 143 will receive a
smaller amount of energy than the amount of energy
applied to the MR element 143 obtained when the fine
projection 121-3 directly hits the MR element 143.
Hence, as shown in Fig. 27D, the read signal has an
10 envelope in which a small abnormal signal due to the
thermal asperity is superimposed thereon. The reduced
abnormal signal can be processed by a signal
processing circuit so that it can be eliminated from
the read signal. As a result, the reproduced signal
15 is less affected by the thermal asperity.

Fig. 28A shows an MR head 130B according to
a seventh embodiment of the present invention. In
Fig. 28A, parts that are the same as those shown in
the previously described figures are given the same
20 reference numbers. The MR head 130B has a structure
configured by taking into consideration a thermal
expansion of the film structure part 134.

There is a possibility that the temperature
of the film structure part 134 is increased when the
25 MR head 130B is in operation. In this case, as shown
in Fig. 28B, the film structure part 134 swells due to
thermal expansion and the end surface 151 is deformed
so as to have a convex shape. The magnitude N_h of the
swelling of the MR element 143 is as indicated in Fig.
30 28B.

As shown in Fig. 28A, the end surface of the
film structure part 134 has a step-like recess 152B
having a step size (depth) Y_3 with respect to the
floating surface 133d. The depth of the step-like
35 recess 152B, that is, the step size Y_3 , is determined
by adding the magnitude N_h of the swelling to the
aforementioned step size Y_1 . Hence, even if the

1 temperature of the film structure part 134 rises while
the MR head 130B is operating, the MR element 143 is
deformed so as to have a swelling close to the
imaginary plane 155, but does not project from the
5 imaginary plane 155. Hence, even if the film
structure part 134 is deformed, a fine projection
located on the magnetic disk 120 will not directly hit
the MR element 143, and the occurrence of an abnormal
signal due to the thermal asperity can be suppressed.

10 The MR head 130B thus configured will be
suitable for a high-temperature circumstance.

Fig. 29 shows an MR head 130C according to
an eighth embodiment of the present invention, in
which parts that are the same as those shown in the
15 previously described figures are given the same
reference numbers. The MR head 130C has a structure
configured by taking into consideration the descending
movement of the MR head 130C after the MR head 130C is
hit by a fine projection, more particularly, an
20 overshooting movement of the MR head 130C which occurs
during the descending movement.

As shown in Fig. 29, the end surface 151 of
the film structure part 134 has a step-like recess
152C having a step size (depth) Y4 with respect to the
25 floating surface 133d. The depth of the step-like
recess 152C, that is, the step size Y4 is defined by
adding a descending movement Z to the aforementioned
step size Y1. That is,

30
$$Y4 \geq Y1 + Z.$$

As shown in Fig. 30A, the fine projection
121-3 (having a relatively large size) hits a portion
in the vicinity of the edge 133d of the floating
35 surface 133d. The MR head 130C is pushed upwardly by
the fine projection 121-3, and then descends. Fig.
30B shows the above movement of the MR head 130C, in

The solid line 171 can be expressed as follows:

15 where A is an overshooting distance which exceeds the amount h of floating caused by the fine projection 121-3, and X is a phase of the MR head 130C defined as follows:

20 where U is the peripheral velocity of the magnetic disk obtained in the position corresponding to the position of the MR head 130C, and f_0 is the resonance frequency of the MR head 130C.

Fig. 31 shows an MR head 130D according to a ninth embodiment of the present invention, in which parts that are the same as those shown in the previously described figures are given the same reference numbers. The end surface 151 of the film structure part 134 has a step-like recess 152D having

1 a step size (depth) Y_5 with respect to the floating
surface 133d. The depth of the step-like recess 152D,
that is, the step size Y_5 is defined by adding the
aforementioned magnitude N_h of the swelling and the
5 descending movement Z to the aforementioned step size
 Y_1 . That is, the step size Y_5 satisfies the following
condition:

$$Y5 \geq Y1 + Nh + Z.$$

10

The MR head 130D has an advantage in that no abnormal signal due to the thermal asperity is generated in an environment in which the MR head 130D is used at a high temperature and the fine projection 121-3 having a relatively large size hits the MR head 130D.

Any of the MR heads 130A - 130D can be used in the magnetic disk apparatus 61 shown in Fig. 13.

Fig. 32 shows results of an experiment
conducted by the inventors. More particularly, Fig.
32 shows a relationship between the abnormal signal
due to the thermal asperity and the step size of the
end surface 151 of the film structure part 134 with
respect to the floating surface 133d. As shown in
Fig. 32, the abnormal signal due to the thermal
asperity can be reduced as the step size is increased.

The step-like recess functions to increase the distance between the end surface of the MR element 143 and the surface of the magnetic disk. The step-like recess does not have a large size, and thus the operation of reproducing the recorded signal from the magnetic disk by the MR element 143 is little affected by the presence of the step-like recess.

It is possible to use the step size Y2 shown in Fig. 26 as a reference in the aforementioned conditions instead of the step size Y1 shown in Fig. 23. In this case, the seventh embodiment of the

1 present invention shown in Fig. 28A has a step size
Y3' which satisfies the following condition:

$$Y3' \geq Y2 + Nh.$$

5

The eighth embodiment of the present
invention shown in Fig. 29 has a step size Y4' which
satisfies the following condition:

10

$$Y4' \geq Y2 + Z.$$

The ninth embodiment of the present
invention shown in Fig. 31 has a step size Y5' which
satisfies the following condition:

15

$$Y5' \geq Y2 + Nh + Z.$$

Fig. 33 shows another magnetic disk
apparatus 61A in which any of the MR heads 130, 130A,
20 130B, 130C and 130D can be provided. In Fig. 33,
parts that are the same as those shown in Fig. 13 are
given the same reference numbers. Fig. 34 shows a
suspension 170 of the magnetic disk apparatus 61A in
which the suspension 170 has a gimbal part 170a that
25 is integrally formed. The suspension 170 is fixed to
an end portion of the rotating arm 163 by, for
example, a caulk joint means. The MR head 130 (130A -
130D) is fixed to the gimbal part 170a of the
suspension 170 by an adhesive. The gimbal part 170a
30 is provided at an end portion of the suspension 170.
The suspension 170 has ribs 170b on both sides of a
central portion of the suspension 170 so that a given
rigidity can be obtained. The suspension 170 has an R
bent portion 170c close to a suspension attachment
35 base thereof. Four patterned wiring lines 170d
extending from the suspension attachment base and the
gimbal portion 170a are provided on the suspension

1 170. Two of the four lines 170d are used for the MR
element 143, and the remaining two lines are used for
the inductive head. Ends 170e of the four patterned
wiring lines 170d are electrically connected to the
5 terminal parts 144' and 148' by electrically
conductive balls 171 of, for example, gold. The MR
head 130 is urged toward the magnetic disk 69 due to
the elasticity of the R bent portion 170c.

The present invention is not limited to the
10 above described embodiments, and variations and
modifications may be made without departing from the
scope of the present invention.

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